Over 100 GB Optical Phase-Change Disc System Realized by Near-Field Technology

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ABSTRACT

Near-Field technology[1] is considered to be most promising method for increasing a recording density on a next-generation optical disc. We have already reported the huge capacity optical disc of 112 GB with using a solid immersion lens (SIL) of high refractive index material and two-axis actuator. When the applicability to optical disc system for next generation is considered, however, we should take notice of not only a recording density but also data transfer rate. The possibility of high data transfer system has been examined by combination two-axis actuator with a well designed servo system. Novel near-field optics with a monolithic dual-laser diode is also proposed.

Keywords: near-field recording, NFR, solid immersion lens, SIL, numerical aperture, NA, gap distance, transfer rate, two-axis actuator, dual-laser diode

1. INTRODUCTION

Data storage technologies in a home electronics have changed greatly in the last few years. A lot of home-AV electronics which adopt the hard disk as the primary memory have appeared, and data capacity for home use increased significantly. Therefore, it is considered that the demand for an optical disc became clearer; cheaper, superior archivability, and huge capacity. On the other hand, not only capacity but also data transfer rate is attached to importance, especially considering the storage of motion video which is considered as an application that needs a mass storage. For example, high transfer rate more than 200Mbps will be necessary for storing a high quality image of “Super High-Vision” with a resolution of 4k×2k.

We have proposed a large capacity optical disc system with a near-field technology[2-6]. The solid immersion lens (SIL) which is made of high index glass[2] is adopted and it is possible to achieve a high numerical aperture (NA) of 1.84. The gap distance between SIL and disc surface is controlled at 25 nm by means of the Total Internal Reflection Method (TIR method)[3, 4]. We used the optical disc drive which has the quite same function except for SIL and TIR method, and were successful to record a high density data of over 100 GB on a phase-change disc[5]. At this experiment, data bit length was 50 nm and linear velocity was 2.2 m/s, and data transfer rate was set to 36 Mbps which was equivalent to 1x rate of Blu-ray system. In order to apply this near-field recording (NFR) system to the above-mentioned application, it is necessary to examine the means to achieve a more high data transfer rate. In this paper, we want to discuss the possibility of increasing data transfer rate in our NFR system. The novel system with dual-laser diode is also examined as one method for this purpose.

2. EXPERIMENTAL

Figure 1 shows a basic setup for evaluating a NFR experiment. We adopted two-wave laser system, the red laser of 780 nm is used for controlling a gap distance by TIR method and the blue laser is used both for achieving a tracking servo and obtaining a RF signal. The tracking error signal is created by a push-pull method. Because characteristics of recording and reproducing are strongly affected by the collection condition of light, the focal point is adjusted by means of beam expander lens. SIL is made of high refractive index glass “S-LAH79” (OHARA INC.). A bulk material was first polished in a spherical shape and a facet was formed while adjusting the thickness. The top surface of SIL was processed to a conical shape for the purpose of dust control[6]. Because of TIR method, polarizing optics was applied. A circular polarization of light which is irradiated on a disc is translated into a linear polarized light by a quarter wave plate (QWP) before detecting by a photo diode. We can select a RF signal or a gap error signal (GES) by choosing a polarizing direction. Roughly speaking, it can be said that our optical system can be easily assembled only with the addition of the GES system to Blu-ray system.

Polycarbonate substrate which has a thickness of 1.1 mm is formed by an injection molding method. We fabricated DC groove with a track pitch of 160 nm by using the electron beam recording (EBR) method[7]. The surface of silicon master disk was observed by a scanning electron microscope and an atomic force microscope. The groove depth was confirmed to be 20 nm and the duty ratio of groove width is estimated to be about 35 %. All recording films, that is Si_3N_4(15 nm) / ZnS-SiO_2(50 nm) / GeSbTe(15 nm) / ZnS-SiO_2(10 nm) / Si_3N_4(10 nm) / Ag(70 nm), are stacked by the magnetron sputtering method. It is easy to adjust the recording film for high speed recording because we examine only a write-once mode in this experiment.

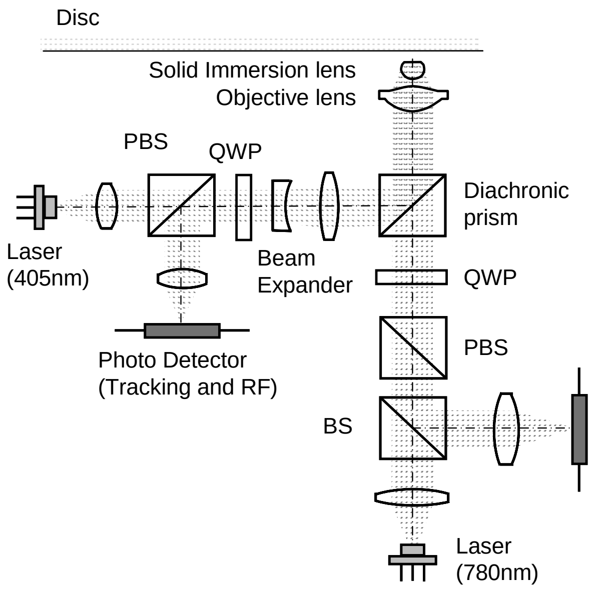

Fig. 1. A schematic drawing of experimental setup for near field read/write test.

3. RESULTS

3.1. STABLITY OF GAP ERROR CONTROLL

We first evaluated the frequency characteristics of the gap servo loop. The 2-axis actuator which is used for conventional optical disc is adopted and a servo system using this actuator is adjusted for our NFR system[8]. Figure 2 shows a close-up picture of our 2-axis actuator. Total weight of moving part including a 2-element lens which is combination of SIL and aspherical lens of NA=0.42 is about 400 mg. We measured the frequency response characteristics of the gap servo system, as shown in Fig.3. The cut-off frequency, gain margin at cut-off frequency, and phase margin are estimated to 5.6 kHz, 5.8 dB, and 26 degrees respectively. In order to estimate the servo performance, the residual error of GES was measured. Figure 4 shows that an initial runout of disc substrate in vertical direction is about 18 μm. We

Fig. 2. A picture of 2-axis actuator for NFR. SIL of NA 1.84 is assembled.

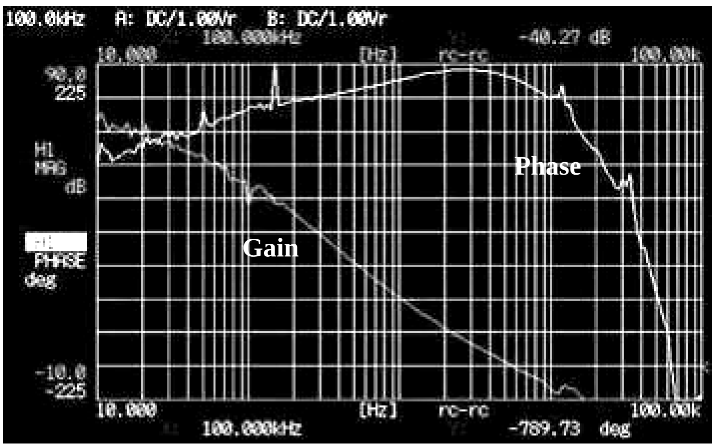

Fig. 3. A bode plot of the gap servo loop. Cut-off frequency of 5.6 kHz, gain margin of 5.8 dB, and phase margin of 26 degrees are confirmed.

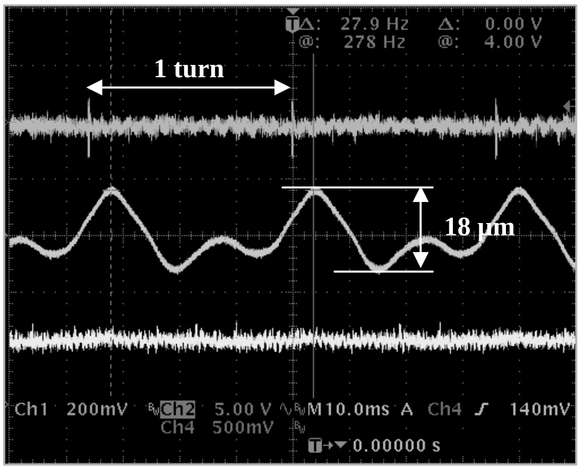

Fig. 4. An initial runout of PC substrate which was measured by laser displacement sensor.

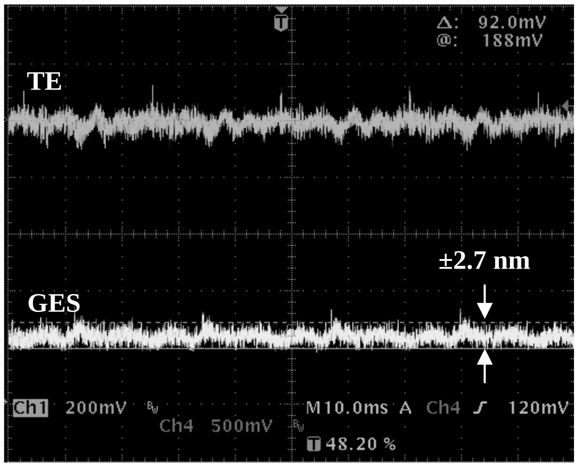

Fig. 5. A residual errors of tracking servo (upper side) and gap servo (lower side) at rotation speed of 2637 rpm (7.26 m/s).

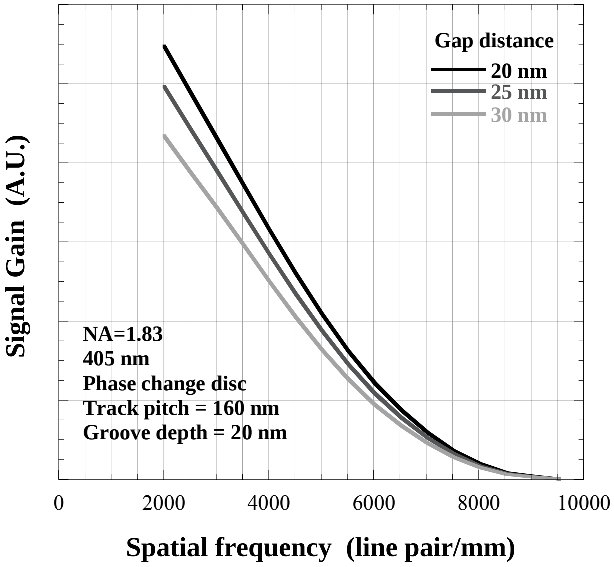

Fig. 6. Calculation result of MTF characteristic under the near field condition with changing the gap distance.

measured a residual GES while changing a rotation speed from 850 rpm to 2640 rpm. The gap distance between SIL and disc surface was adjusted to keep 20 nm. The residual error of GES at rotation speed of 850 rpm, 1270 rpm, 1700 rpm, and 2640 rpm was 2.4 nm, 3.4 nm, 4.4 nm, and 5.4 nm respectively. From these results, it is possible to estimate the servo gain to be more than 75 dB and we could find that these values consistent with theoretical servo gain.

To confirm the stability of a gap servo system from not only a comprehensive viewpoint but also a microscopic viewpoint, the stability of reproducing signal was also evaluated. The envelope fluctuation of reproducing signal was small enough and it was found to be ±7 % at rotation speed of 1700 rpm in a comprehensive evaluation. We focused the signal fluctuation in a small area. When the signal is analyzed in detail, the fluctuation of the reproducing signal is sometimes observed as an error within the small range in one or two bits. Figure 6 shows the calculated results of modulation transfer function (MTF) at gap distance of 20, 25, and 30 nm. We can understand that the reproducing signal decreases by 10 % when the gap distance increases 5 nm. We examined whether the main cause of this fluctuation of reproducing signal in several bits was unstable of the gap control. In Fig. 7, we show an example of the reproducing signal that was measured at the timing of the few bit error, when a carrier

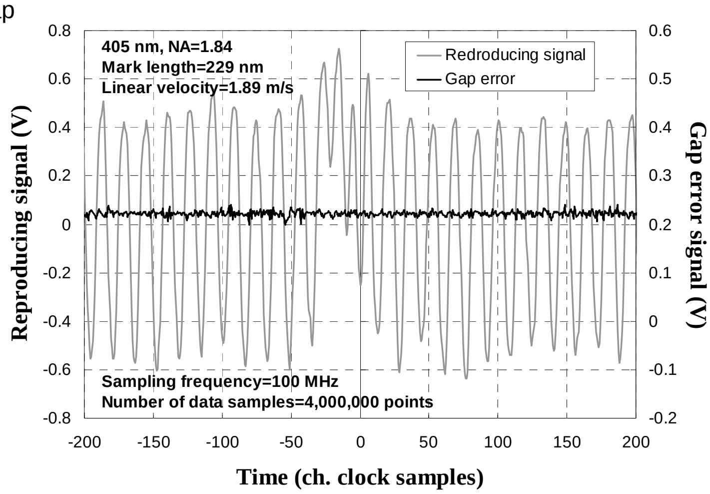

Fig. 7. Fluctuation of reproducing signal in the range of few bits. GES is measured simultaneously.

signal of 0.229 nm was recorded. The fluctuations of both the amplitude and the DC level of the reproducing signal are observed in a short period. At the same timing, GES was also monitored, but we could not find any fluctuation of it. We measured this phenomenon at several mark length and confirmed that no fluctuation of GES was observed. We concluded that the stability of gap servo system was also confirmed even from a microscopic viewpoint.

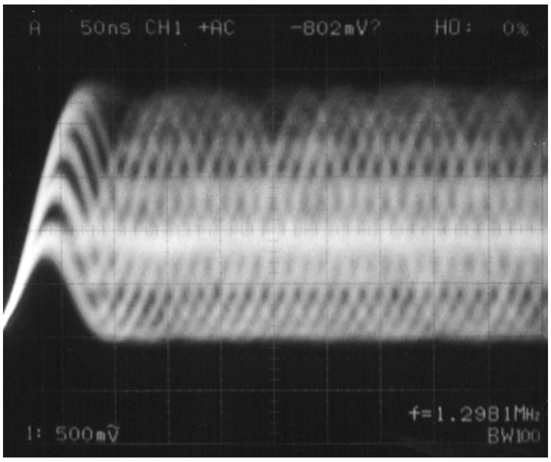

Fig. 8. Eye pattern when 17pp signal of 80.6 Gbit/in^2 is recorded on phase change media by transfer rate of 36 Mbps. (one track recording)

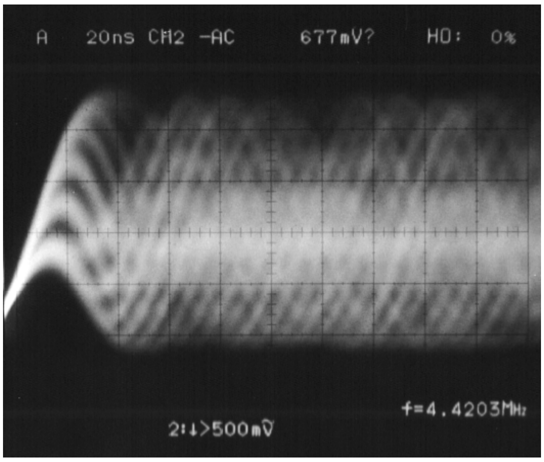

Fig. 9. Eye pattern when 17pp signal of 80.6 Gbit/in^2 is recorded on phase change media by transfer rate of 72 Mbps. (one track recording)

3.2. EXAMINATION AT HIGH TRANSFERRATE

In order to evaluate the possibility of high data transfer rate, we recorded the modulated data by 17pp code with changing both the linear velocity and the channel clock. Figure 8 and figure 9 are the observed eye pattern at the data transfer rate equivalent to 36 Mbps and 72 Mbps respectively. The recording density was kept at 80.6 Gbit/in^2. In the case of transfer rate of 36 Mbps, as shown in Fig. 8, the linear velocity was set to 2.2 m/s and channel clock of 66 MHz was selected. Both the recording power and the pulse shape of irradiated laser were adjusted while measuring a bit error rate. We estimated the bit error rate of 1×10^{-4} which was measured by using a combination of both PR-(1221) and a limit equalizer of 9-tap. In the case of 72 Mbps in Fig. 9, both the linear velocity of 4.4 m/s which corresponds to 1698 rpm at the radius of 25 mm and the channel clock of 132 MHz were selected. We observed a nice eye pattern and the sufficient low bit error rate of 1.88×10^{-4} were measured. It was found that the recording with high transfer rate of 72 Mbps was feasible to the same extent as the case of 36 Mbps.

We also tried to record with a transfer rate of 108 Mbps that is equivalent to three times rate of Blu-Ray. The channel clock of 198 MHz was adopted and disc rotation speed was set to 2888 rpm which was understood as the upper limitation of gap servo system from our previous examination. Figure 10 shows a readout eye pattern at the recording density of 73.3 Gbit/in^2 (that is, 102 GB on 120 mm diameter disc). We were able to see the fairly excellent reproducing waveform and it is considered that this result shows the possibility of an optical disc system with both a high density and a high data transfer rate. In other words, it

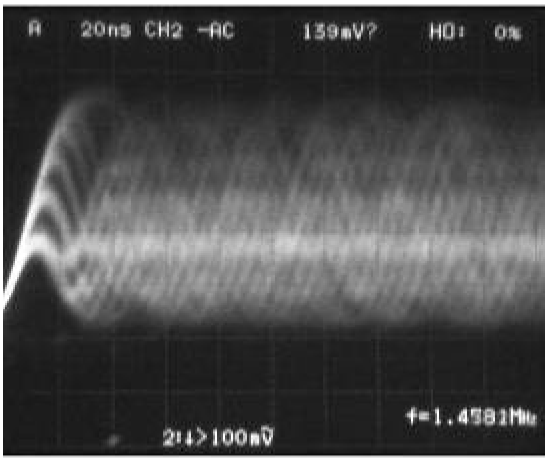

Fig. 10. Eye pattern when 17pp signal of 73.3 Gbit/in^2 is recorded on phase change media by transfer rate of 108 Mbps. (one track recording)

will be possible to realize the optical disc system of 100 GB and 100 Mbps.

4. DISCUSSION

We could decide that it would be possible to achieve a high data transfer rate of 100 Mbps by means of high performance actuator and servo system. However, the higher transfer rate system than 200 Mbps should be achieved if the applying to a future recording system of high quality 4k×2k image is desired. We proposed the dual-channel NFR system with a monolithic dual-beam blue laser diode[9] as a technical answer for high transfer rate. Table 1 shows the specifications of the newly developed monolithic dual-beam blue laser diode. Each emitter has almost same characteristics as that of commercially available blue-violet laser diodes. The maximum output power 65 mW (Pulse) corresponds to 8.5 mW (Pulse) on the top surface of the SIL inside. The optics of our dual-channel NFR system is shown in Fig. 11. The pin-holes select one of the beams from the emitters, so that automatic power control (APC) of laser light can be applied individually to the two focused light spots on the SIL surface. As well as single beam tester as shown in Fig. 1, a laser diode of 660 nm is utilized for deriving GES, and it is separated from the optics of 412 nm. We used a SIL whose refractive index and diameter are 2.070 at 412 nm and 0.9 mm, respectively. The total NA of the objective lens is 1.84. The magnification of our optics

Table 1. Specifications of dual-beam blue laser diode.

Emitter distance	96 µm
Wavelength	412 nm
Maximum output power	65 mW (Pulse)
$\theta_{\perp}$, $\theta_{//}$	22 deg, 9 deg (typical)
Case outline	ø9 mm

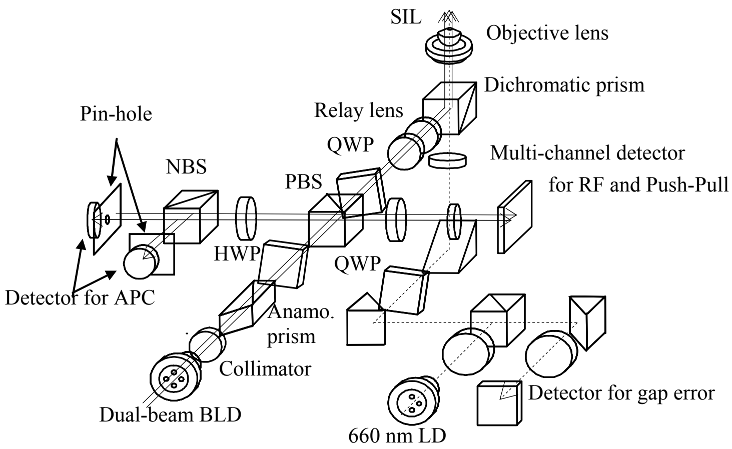

Fig. 11. Schematic drawing of an optical set-up for a dual-channel NFR system.

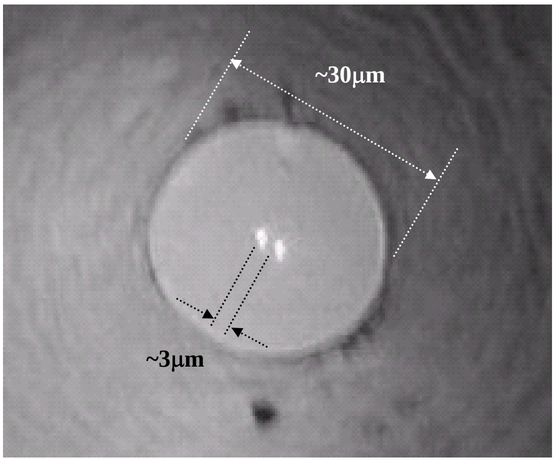

Fig. 12. The micrograph of top surface of a SIL. Light spots from dual-beam laser are observed.

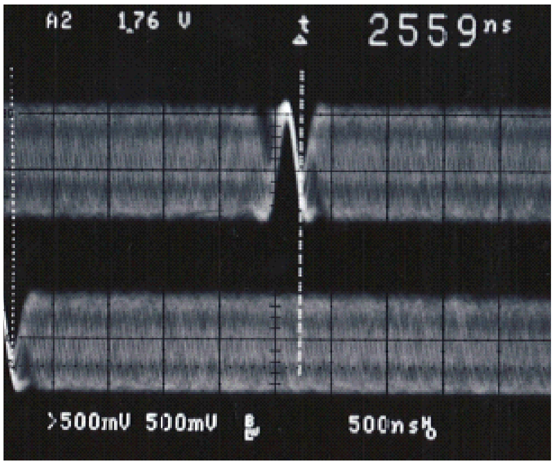

Fig. 13. Reproducing waveform from 50 GB Si-ROM by dual-beam system when each beam is aligned on the same data track.

converts emitter distance 96 μm of the laser diode to a distance 3.1 μm between the focused light spots on the SIL surface. Figure 12 is the observed light spots on the top surface of the SIL. The distance between two laser spot is able to be estimated by reproducing signals as shown in Fig. 13. We observed a reproducing wave form from Si-ROM disc of 50 GB which was fabricated by EBR system. When each beam is aligned on the same data track, we can obtain a spot distance as a time delay of reproducing signal. From Fig. 13, because a linear velocity of disc is 1.2 m/s, we can calculate the spot distance is 1.2 m/s×2559 ns=3.07 μm and it is equal to the value exactly designed.

Using this dual-beam NFR system, we succeeded in achieving a complete dual-channel recording. Each channel was modulated by the EFM code or 17pp code, and confirmed each data was recorded in a separate track on the phase-change disc simultaneously. The channel clock was 66 MHz and the linear velocity was 3.1 m/s, which corresponds to 80 GB capacity and to 36 Mbps/channel in the case of 17pp modulation. Figure 14 shows the measured result of waveforms reproduced by dual-beam laser. We designed the arrangement of the spot so that the influence of the aberration might become small enough. From these waveforms, the arrangement of optics seems to be successful because we could not see any degradation of signal. We can conclude that this dual-beam system is a promising method which can increase a data transfer rate up to 200 Mbps.

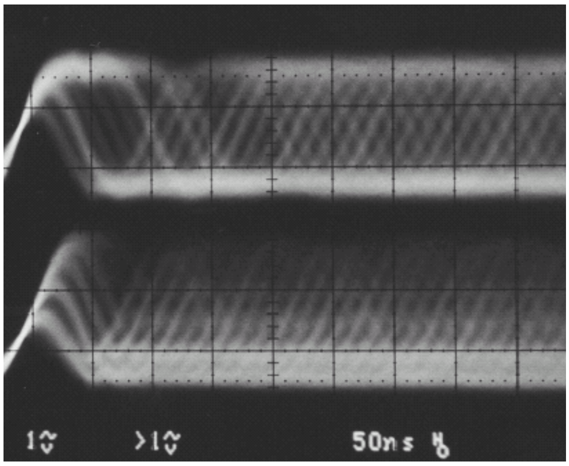

Fig. 14. Result of simultaneous recording by dual-channel. One channel recorded an EFM data (upper side) and other channel recorded 17pp data (lower side) with the same channel clock.

5. CONCLUSION

The high-speed technology of transfer rate in the NFR system was examined. As a result, the focus residual error at the transfer rate of 72 Mbps that corresponds to Blu-Ray×2 was ± 4.4 nm, and it was found that the signal degradation because of the gap fluctuation could be controlled to less than 10 %. And the possibility of higher transfer rate of 108 Mbps that corresponds to Blu-Ray×3 was also presented. Novel NFR system adopting a monolithic dual-beam blue laser diode was demonstrated. The possibility of achieving the next generation optical disk system of more than 100 GB and 200 Mbps was shown by combining proposed new NFR systems.

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